Active Network Management

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Course outline

1. Introduction to Smart Grid
2. Smart grids and real case studies in UK
3. Integration of Energy Storage and DSR
4. Active network management
5. Advanced power flow
6. Integration of Renewable Energy Sources

Introduction to *Active Network Management*

No accurate definition. What majority of researchers say?

Active Network Management

Active: Literal meaning: mobile, dynamic, committed. How does the grid become *ACTIVE*?

Inclusion of distributed energy resources such as distributed generation (bi-directional power flow), renewables (uncertainty), electric vehicles (mobile and dynamic), storage (committed)

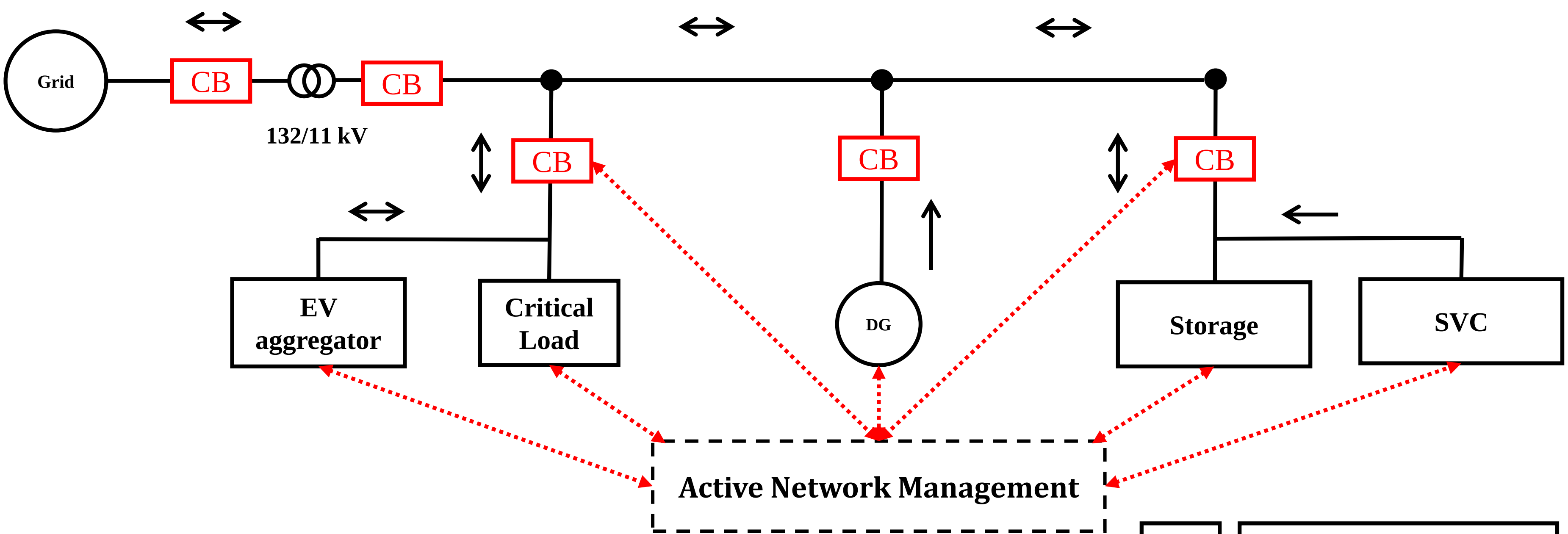
Network Management: Managing the grid

It involves monitoring and control, taking preventive and corrective actions to keep the system stable and safe.

Active Network Management:

Managing an active grid which is open to new stochastic generation, flexible, adaptable, autonomous, and intelligent

Functions involved in Active Network Management



CB	Circuit breaker/Switch
→	Power flow
←···→	Information flow
SVC	Static VAR compensator

- **Power flow management**
- **Generation dispatch**
- **Voltage control**
- **Network reconfiguration**
- **Fault management**
- **Demand side management**

To *control* and *manage* network equipment in normal conditions to enhance the utilisation of the network assets and minimise the requirement for their reinforcement

Motivation and Challenges for Active Network Management

Motivation

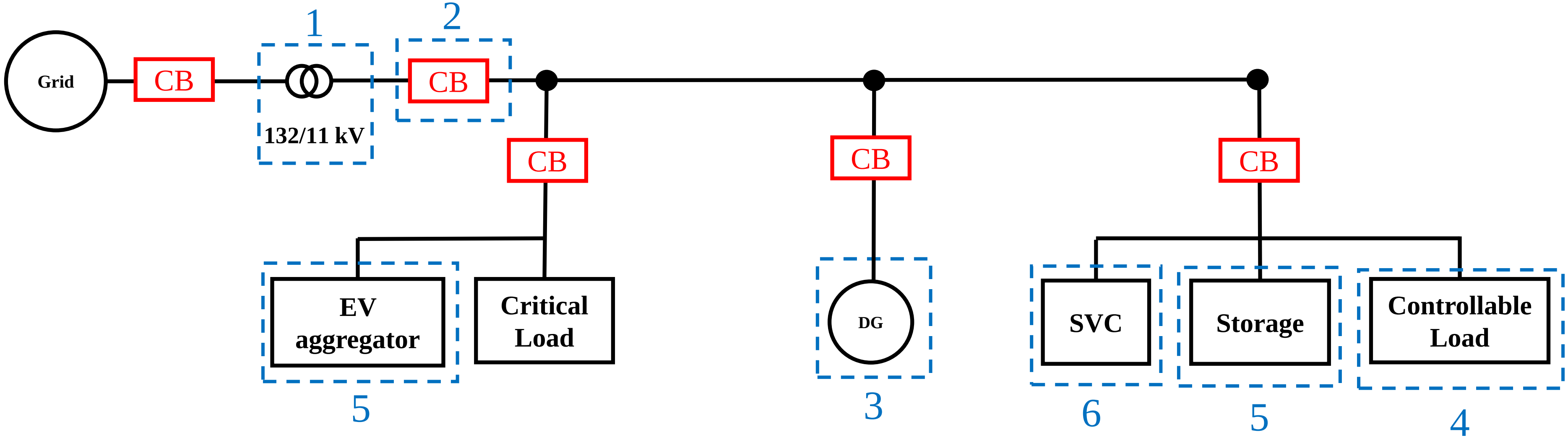
- Increasing power demand from the customers
- Increasing environmental concerns (promotion of renewable energy sources)
- Reduction in capital investment
- Making the best use of the existing resources or assets

Challenges

- Constraint management (network as well as commercial)
- Maintaining security and quality of power supply
- Encourage customer participation (Ensure customer satisfaction)
- Communication infrastructure (Security and increase in capital investment)
- Data management (Derive information from the data)

Source: Smarter Grid Solutions

Tools for Implementation



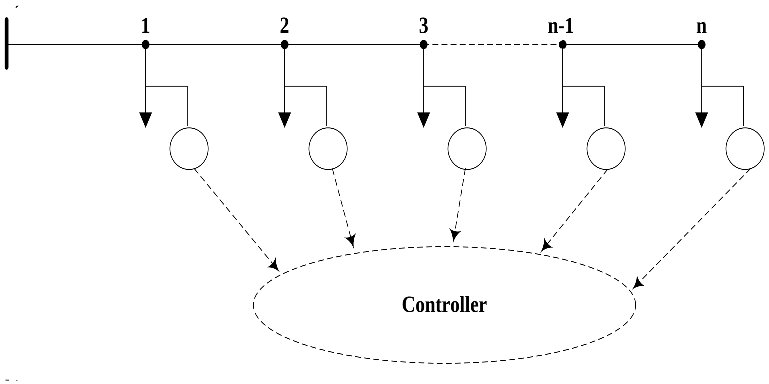
Control **and** ***manage*** **network equipment**

1. Tap changers (Manual as well as automatic)
2. Circuit breakers (network reconfiguration)
3. Distributed generation (Active and reactive power)
4. Controllable loads (Non-critical)
5. Electric vehicles and battery energy storage
6. FACTS devices (SVC or UPFC)

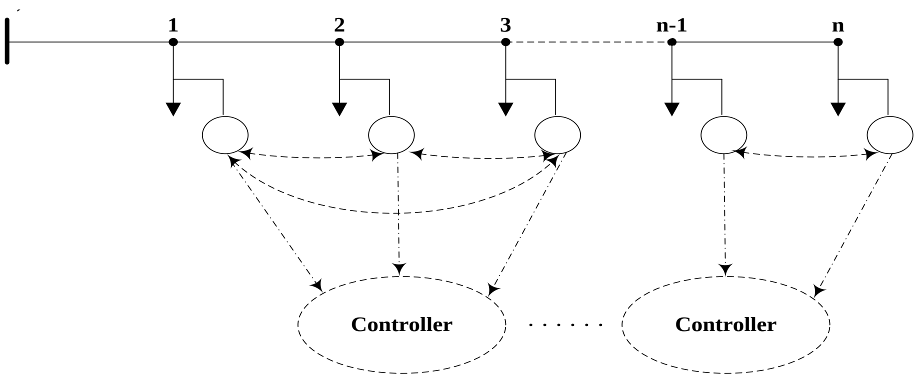
As the number of devices or equipment increases, the task becomes more challenging

Control Architecture

Centralized architecture



Decentralized architecture



Advantages of centralized architecture:

- Provides optimal decisions
  - Wider view helps to make more informed decisions

Disadvantages of centralized architecture:

- Requires high processing ability.
- Less tolerant to communication failure.
- Higher computation time.

Hybrid or distributed approaches are also proposed and tested for different applications/functions.

Architecture may depend on application

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State of the art: Industry

ABB — Network Manager

ALSTOM — e-terra

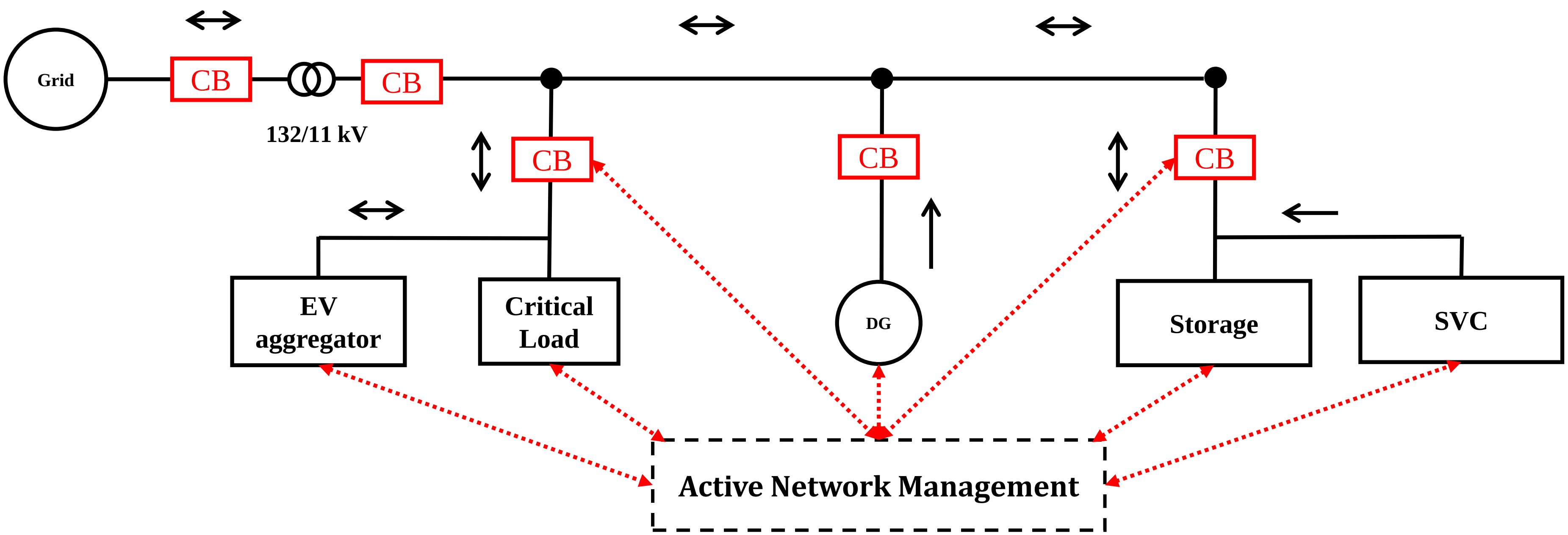
SIEMENS — Intelligent Control Centre Technology

GE — Energy Management Solutions

Schneider Electric — Energy Management System

- Look at a wider aspect from communications, optimization, data analysis, security and provide a complete package as a solution
- Provide Software as well as hardware solutions
- Solutions are in the form of real time, autonomous and deterministic control decisions

Power Flow Management and Generation Dispatch



- Determine which generator to use when, considering network, demand and generation constraints.
- Challenging due to introduction of different power sources: Grid, DG, Storage, EVs, SVC (reactive power) etc.
- Uncertainty of generation and load, criticality of loads, complex network constraints, cost management.

Multi-objective, multi-constraint problem!

Logan will discuss this in detail

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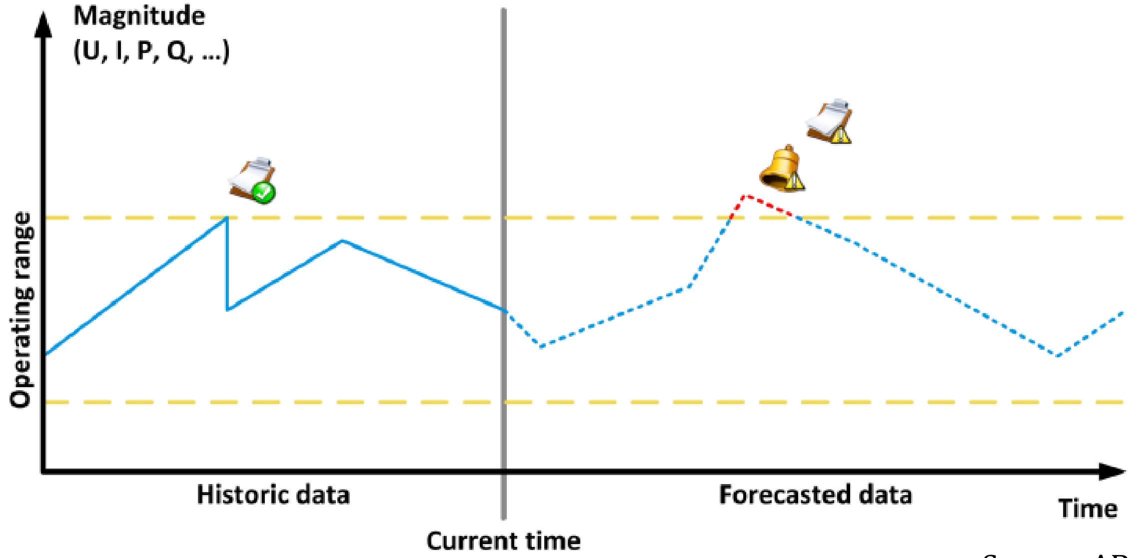
Voltage Control

- Distributed energy resources alter the power flow and the voltage profile in the distribution systems.
- Requires voltage and reactive power control equipment to operate based on a coordinated control using forecasting, optimization and remote control.

Tap changers

Capacitor banks

FACTs devices

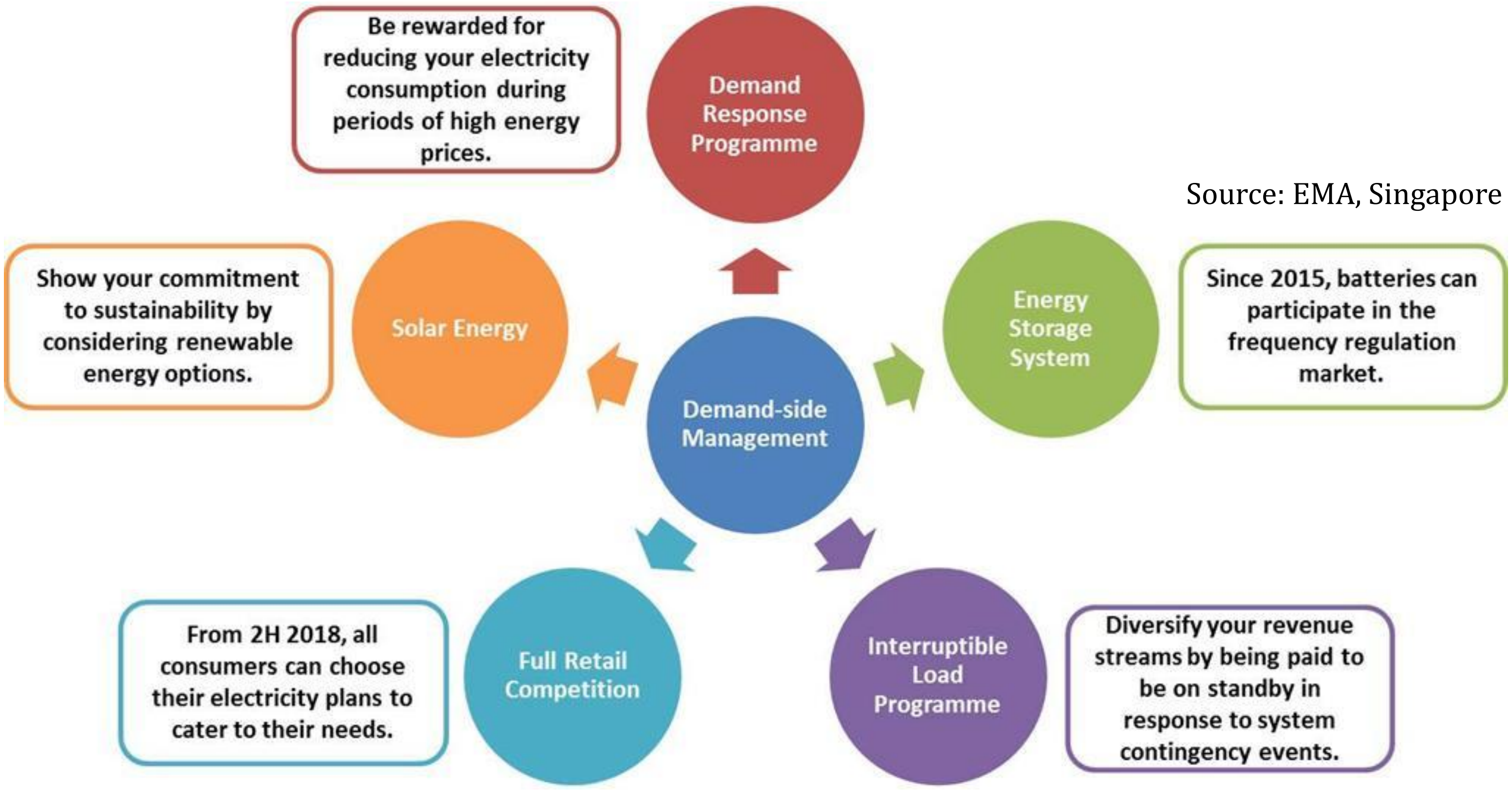


Source: ABB

Phil discussed about this yesterday

Demand Side Management

- A mitigating tool for energy imbalance and peak load management.
- Refers to initiatives and technologies that encourage consumers to optimise their energy use.



Source: EMA, Singapore

T. Logenthiran, D. Srinivasan and T. Z. Shun, "Demand Side Management in Smart Grid Using Heuristic Optimization," in IEEE Transactions on Smart Grid, vol. 3, no. 3, pp. 1244-1252, Sept. 2012.

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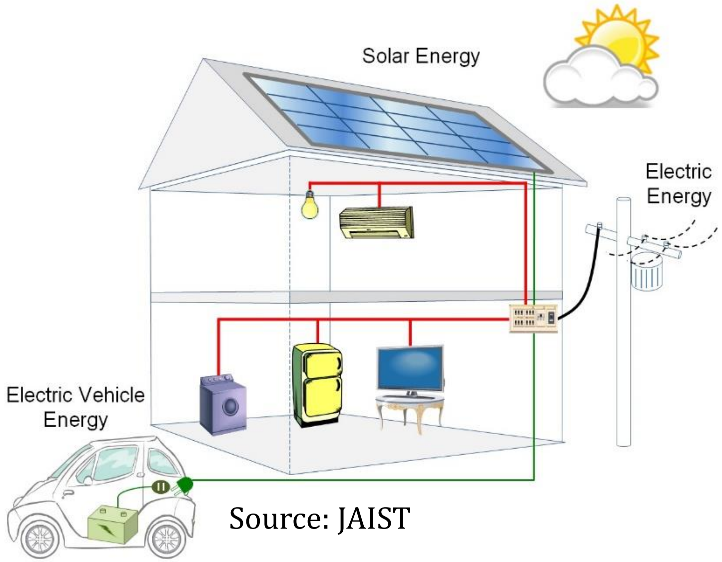
Demand Side Management

<u>Home Energy Management</u> ≈ Demand Side Management at home level



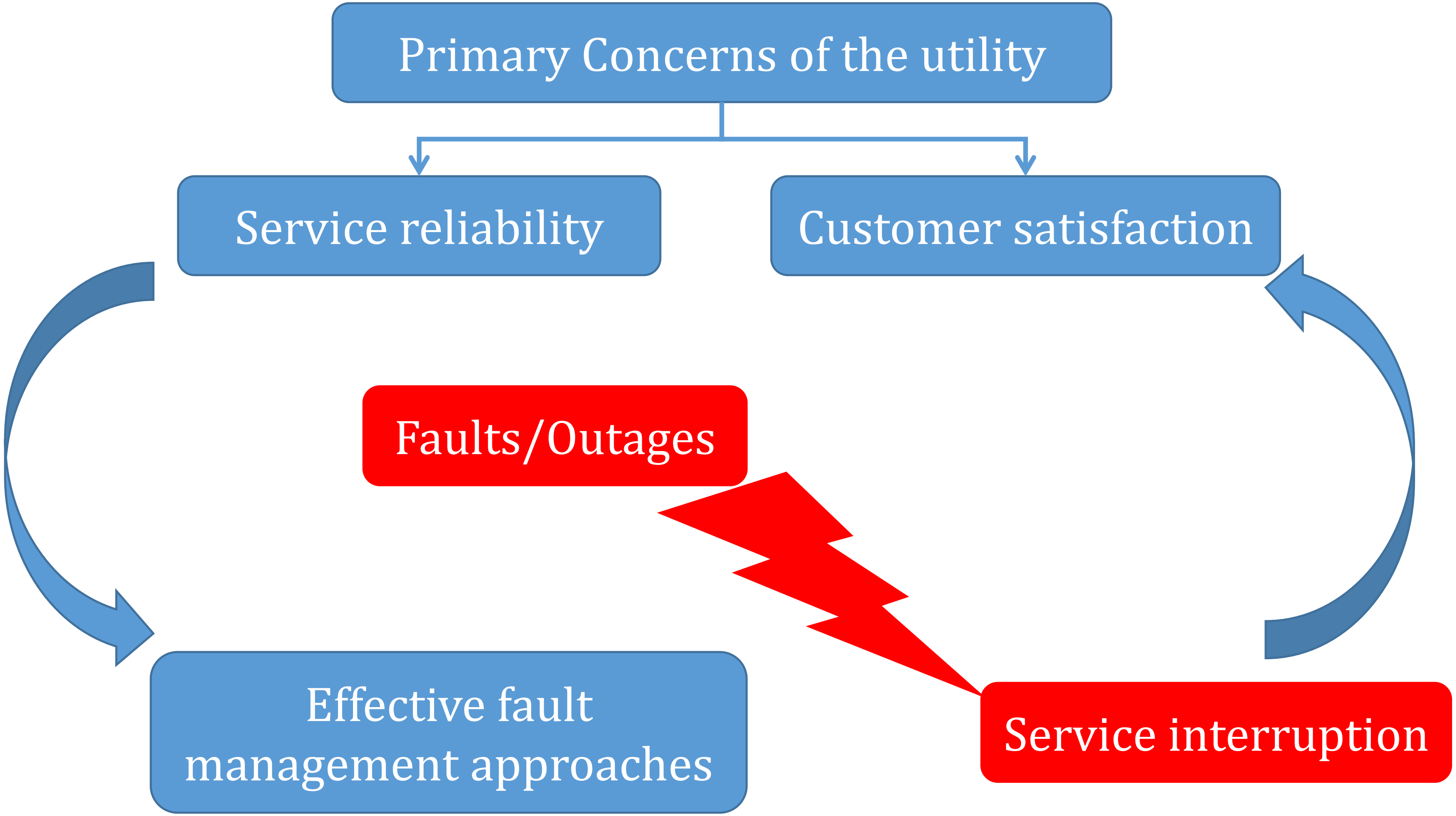
Source: JAIST

- Aim is to minimize the electricity bill
- Use artificial intelligence (Neural network techniques) to analyse load data and identify the usage at appliance level
- Non-intrusive load monitoring to make the process faster and cost effective
- Suggest optimal usage schedule considering individual appliance usage and customer needs
- Use of MAS for decision making

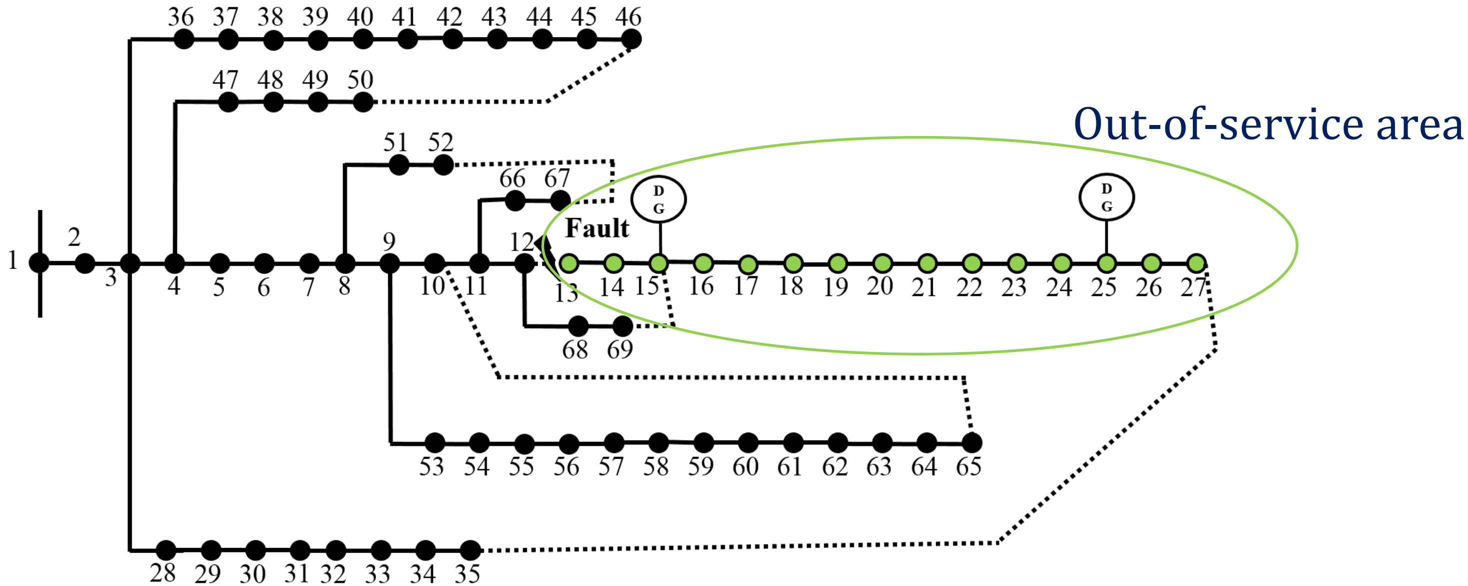
W. Li, T. Logenthiran, W. L. Woo, V. T. Phan and D. Srinivasan, "Implementation of demand side management of a smart home using multi-agent system," 2016 IEEE Congress on Evolutionary Computation (CEC), Vancouver, BC, 2016, pp. 2028-2035.

L. Y. Hui, T. Logenthiran and W. L. Woo, "Non-Intrusive Appliance Load Monitoring and Identification for smart home," 2016 IEEE 6th International Conference on Power Systems (ICPS), New Delhi, 2016, pp. 1-6.

Fault Management and Network Reconfiguration



Fault Management



Fault occurs → Detection and Isolation → Restoration of power supply to the unfaulted area

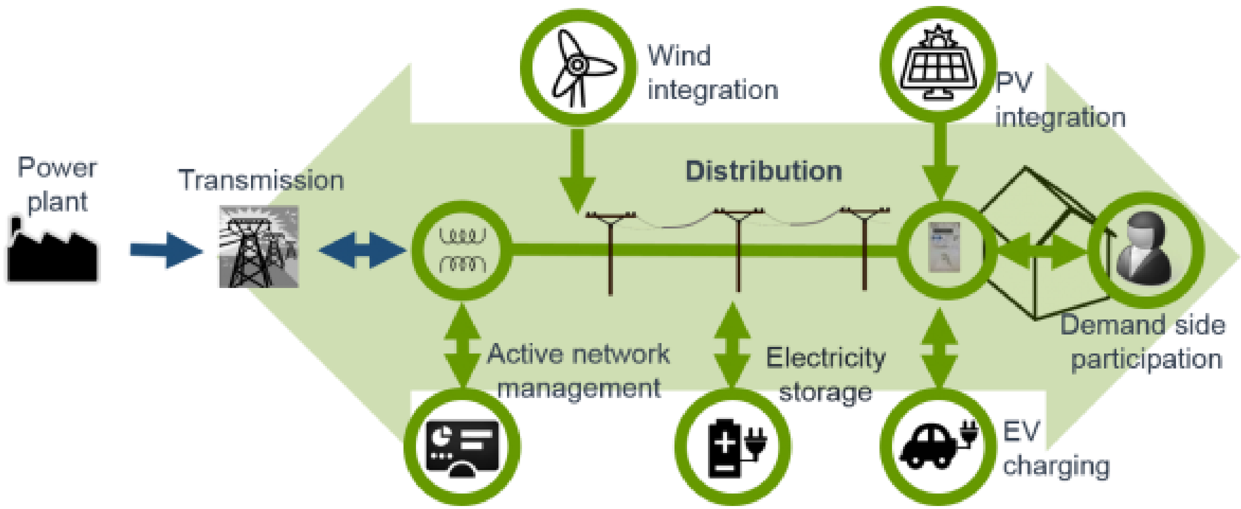
This process is called Fault Management

Recently, concept of self-healing and resiliency of the grid has also become very important

Anticipation of fault: data analysis using machine learning

X. Wang; S. McArthur; S. Strachan; J. Kirkwood; B. Paisley, "A Data Analytic Approach to Automatic Fault Diagnosis and Prognosis for Distribution Automation," in IEEE Transactions on Smart Grid , in press

Fault Management



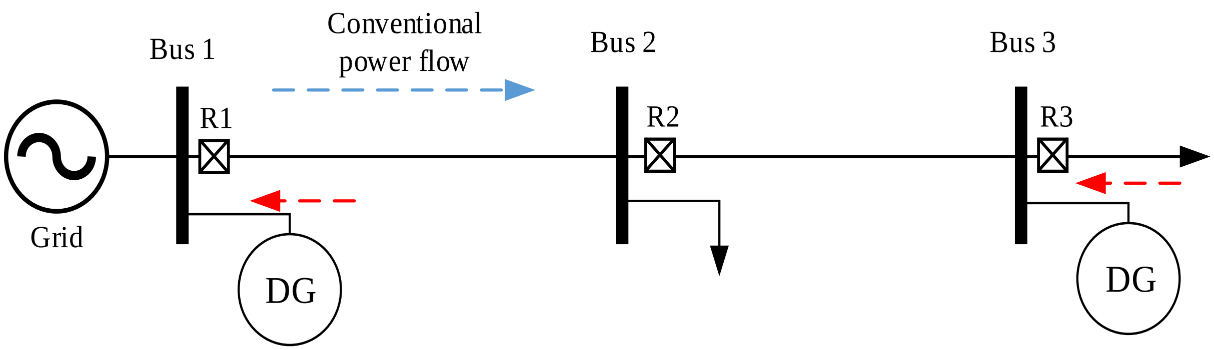
Network complexity has increased: DGs (dispatchable and renewable), Loads (critical and non-critical), Energy Storage (Battery storage and EVs)

Uncertainty of load demand, power generated by renewable DGs, availability of EVs, and outage duration

Task becomes more complex and challenging

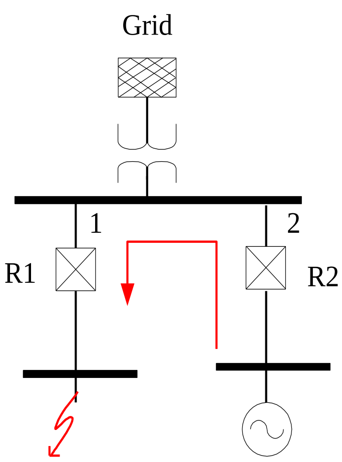
Detection and Isolation

Integration of DGs in traditional distribution feeder

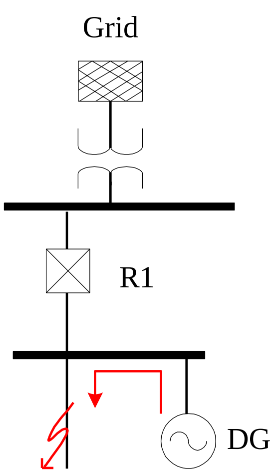


- Bi-directional fault current
- Reduced/increased fault current levels
- Changing fault current levels

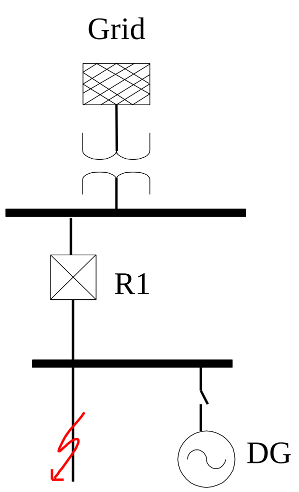
Over-reach



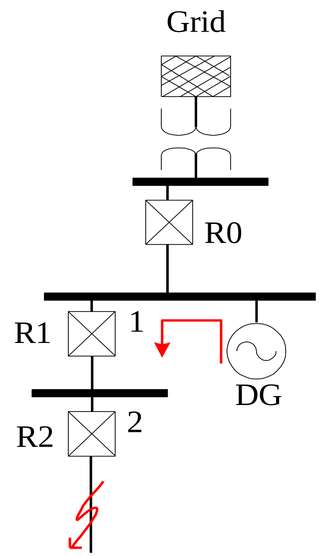
Under-reach



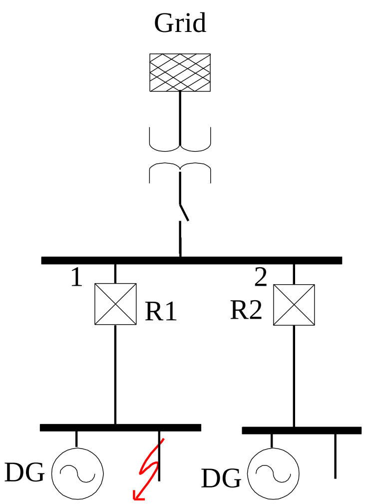
Loss of DGs



Loss of relay coordination



Islanding-effect



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Detection and Isolation

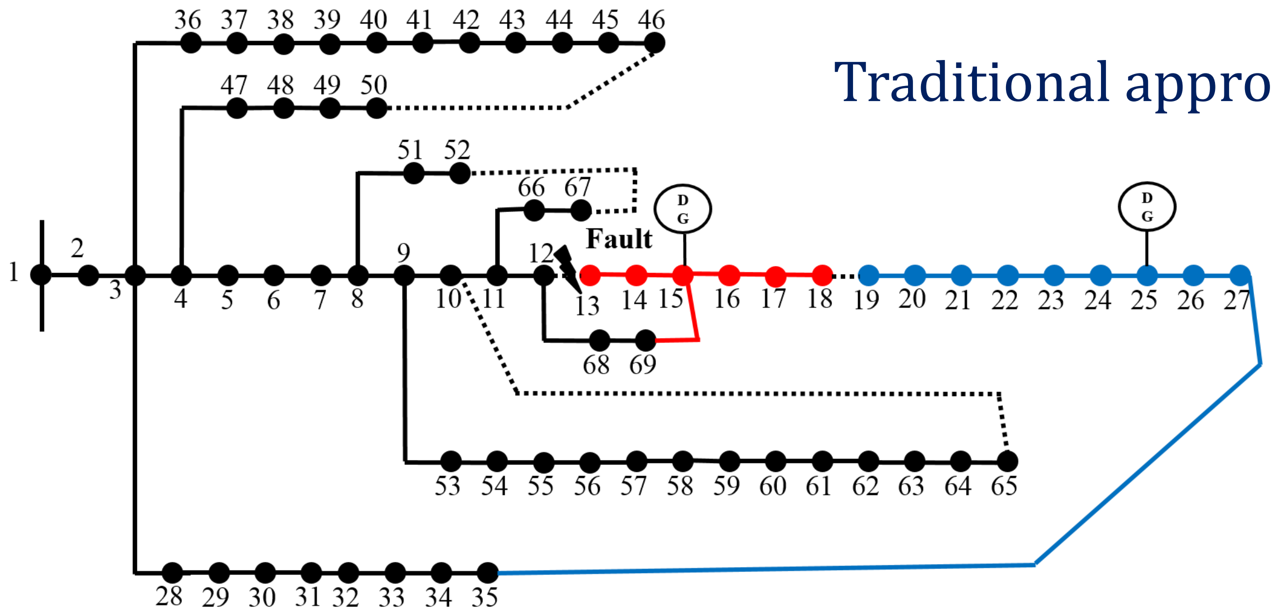
Adaptive protection schemes are required which consider power available from DGs and voltage level at buses to determine current and time settings.

D. S. Kumar, D. Srinivasan and T. Reindl, "A Fast and Scalable Protection Scheme for Distribution Networks With Distributed Generation," in IEEE Transactions on Power Delivery, vol. 31, no. 1, pp. 67-75, Feb. 2016.
D. S. Kumar, D. Srinivasan, A. Sharma, and T. Reindl, "An Adaptive relaying scheme for the protection of meshed distribution system," in IEEE Transactions on Power System, under review.
H. M. Zeineldin; H. H. Sharaf; E. El-Saadany, "Protection Coordination for Microgrids with Grid-Connected and Islanded Capabilities using Dual Setting Directional Overcurrent Relays," IEEE Transactions on Smart Grid, early access.

Service restoration

- Process of restoring power supply to out of service area
- Restore maximum load as quickly as possible

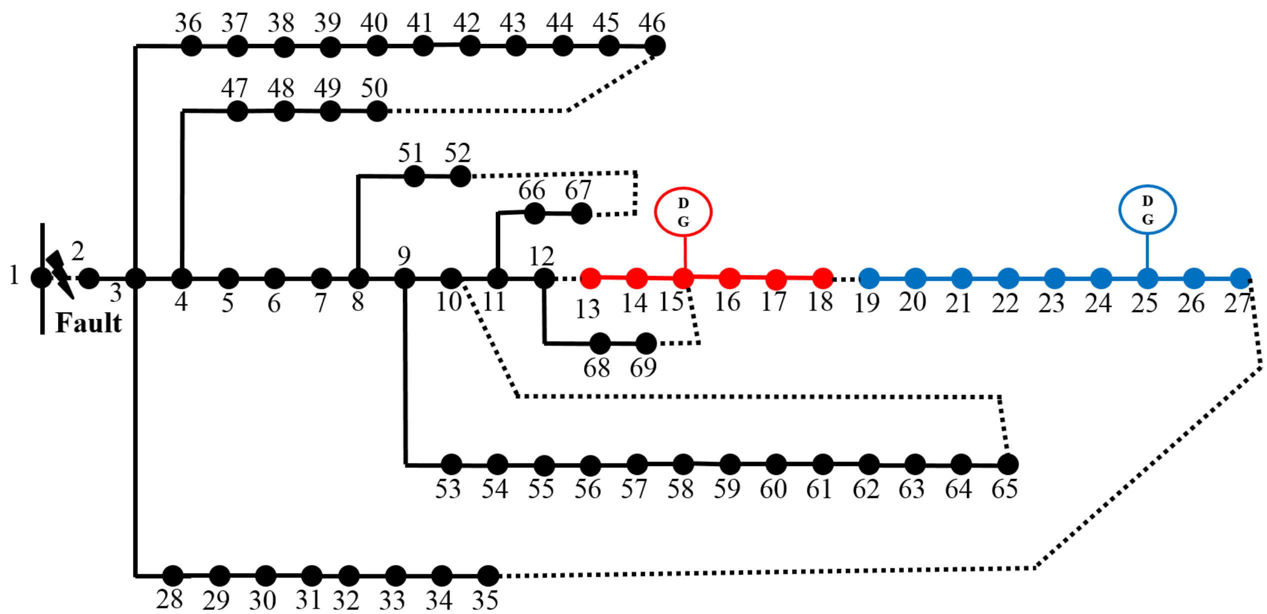
Traditional approach



- Back-up feeders for restoration via network reconfiguration
- DGs were disconnected from the system

Service restoration

What if fault is on grid side?



- IEEE Std. 1547.6 – 2011 provided Islanding guidelines
- DGs to supply power to local loads and assist restoration through islanding

Problem formulation

Challenge: develop efficient restoration strategies to determine islands which can restore maximum load in shortest time possible

- **maximum load** → Load can be critical (high priority) or non-critical (low priority) → Maximize priority load restored
- **shortest time possible** → Time governed by number of switching operations → Minimize the number of switching operations

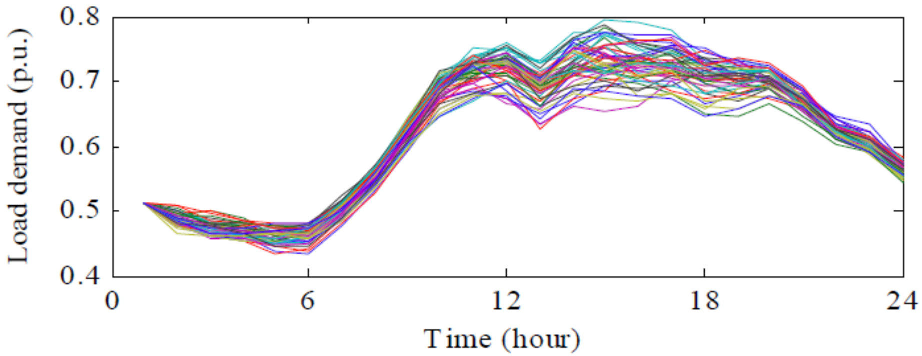
W. H. Chen, “Quantitative Decision-Making Model for Distribution System Restoration,” *IEEE Trans. on Power Syst.*, vol. 25, no. 1, pp. 313-321, 2010.

C. Chao-Shun, L. Chia-Hung, and T. Hung-Ying, “A rule-based expert system with colored Petri net models for distribution system service restoration,” *IEEE Trans. on Power Syst.*, vol. 17, no. 4, pp. 1073-1080, 2002.

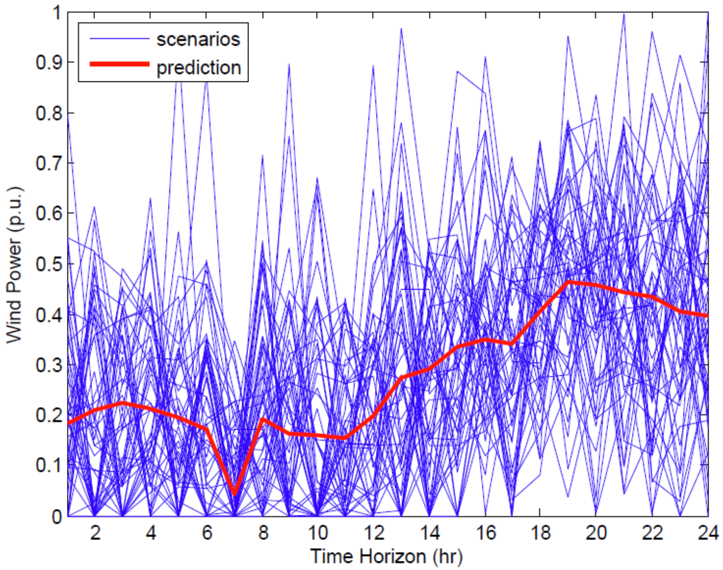
Motivation

- Service restoration is generally solved in the literature considering a deterministic environment*

- System operating conditions, such as load demand and power generated from the renewable DGs (such as wind and solar) do not remain constant during restoration process



Uncertainty of load demand



Uncertainty of wind power

*T. T. H. Pham, Y. Besanger, and N. Hadjsaid, "New Challenges in Power System Restoration With Large Scale of Dispersed Generation Insertion," IEEE Trans. on Power Syst., vol. 24, no. 1, pp. 398-406, 2009.

P. L. Cavalcante, et.al., "Centralized Self-Healing Scheme for Electrical Distribution Systems," IEEE Trans. on Smart Grid, vol. 7, no. 1, pp. 145-155, 2016.

Motivation

- An effective way to handle the system uncertainties is storage devices in the form of Battery energy storage (BES) and electric vehicles (EVs)

- Furthermore, in the presence of uncertain system operating conditions and storage devices, the uncertainty of outage duration also plays a vital role.

- The motivation is to solve the service restoration problem in an uncertain environment using DG islanding in the presence of various distributed energy resources (DERs).

- DERs used are dispatchable DGs, renewable DGs, battery energy storage, and electric vehicles

[5] Y. Zhang, Z. Y. Dong, F. Luo, Y. Zheng, K. Meng and K. P. Wong, "Optimal allocation of battery energy storage systems in distribution networks with high wind power penetration," in IET Renewable Power Generation, vol. 10, no. 8, pp. 1105-1113, Sep 2016

[6] M. González Vayá and G. Andersson, "Self Scheduling of Plug-In Electric Vehicle Aggregator to Provide Balancing Services for Wind Power," in IEEE Trans. on Sust. Energy, vol. 7, no. 2, pp. 886-899, April 2016

[7] I. Atzeni, L. G. Ordóñez, G. Scutari, D. P. Palomar, and J. R. Fonollosa, "Demand-side management via distributed energy generation and storage optimization," IEEE Transactions on Smart Grid, vol. 4, no. 2, pp. 866-876, 2013.

[8] Y. Xu, and C. Singh, "Adequacy and economy analysis of distribution systems integrated with electric energy storage and renewable energy resources," IEEE Transactions on power systems, vol. 27, no. 4, pp. 2332-2341, 2012.

Solution approach

- Classical optimization and metaheuristic techniques are proposed to determine the restoration strategy (islands to be restored)
  - Provide optimal solutions, however, require high computational time
  - Centralized approach, prone to single point failure

- A multi-agent system (MAS) approach can be used to overcome the aforementioned especially in presence of several DERs
  - Distributed approach
  - Parallel behavior
  - Flexibility

T. T. H. Pham, Y. Besanger, and N. Hadjsaid, "New Challenges in Power System Restoration With Large Scale of Dispersed Generation Insertion," IEEE Trans. on Power Syst., vol. 24, no. 1, pp. 398-406, 2009.
H. Falaghi, M. Haghifam, and C. Singh, "Ant colony optimization-based method for placement of sectionalizing switches in distribution networks using a fuzzy multiobjective approach," IEEE Trans. Power Del., vol. 24, no. 1, pp. 268–276, Jan. 2009.
Y. Xu and W. Liu, "Novel Multiagent Based Load Restoration Algorithm for Microgrids," IEEE Trans. on Smart Grid, vol. 2, no. 1, pp. 152-161, March 2011.

Solution approach

- The main goal is to solve the service restoration problem in an uncertain environment using intentional islanding in the presence of various DERs

- Develop a MAS framework to solve the following problems:

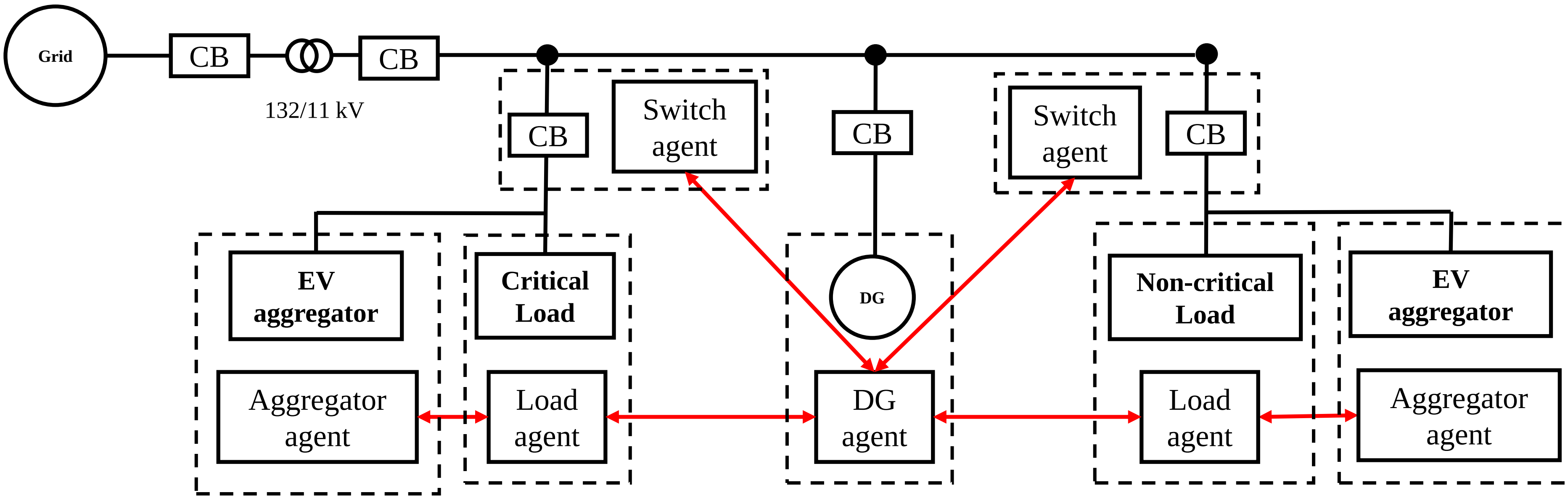
1. Service restoration problem in deterministic environment

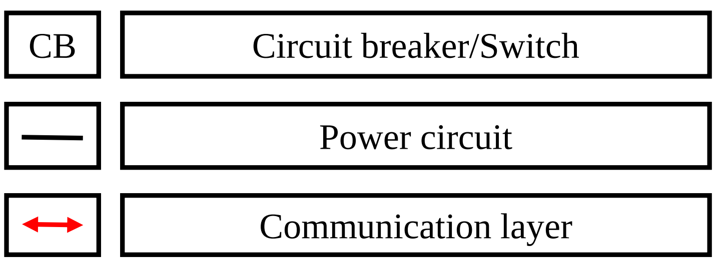
2. Service restoration problem under uncertainty of load demand and power generated by RDGs

3. Service restoration problem under uncertainty of outage duration

Service restoration in deterministic environment

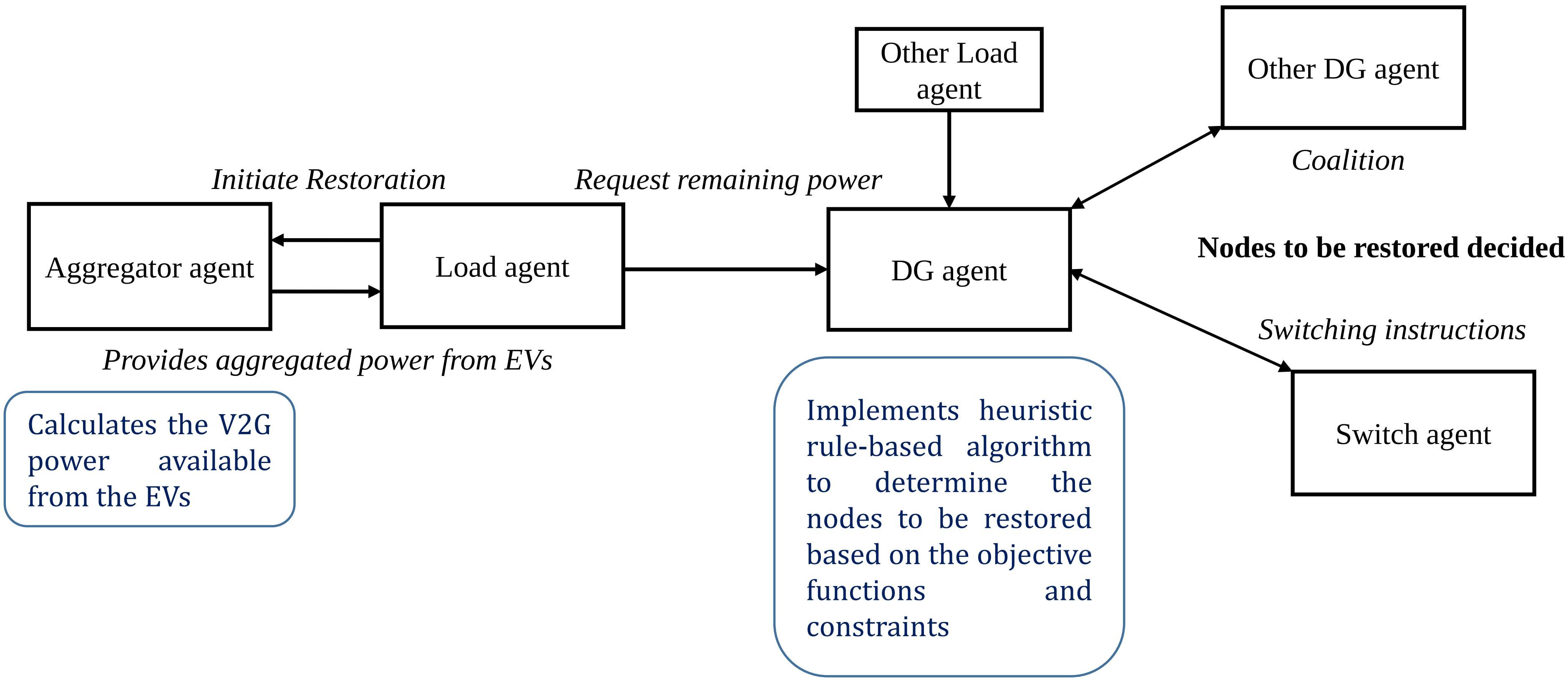
Agents: DG agent, Load agent, Aggregator agent, and Switch agent





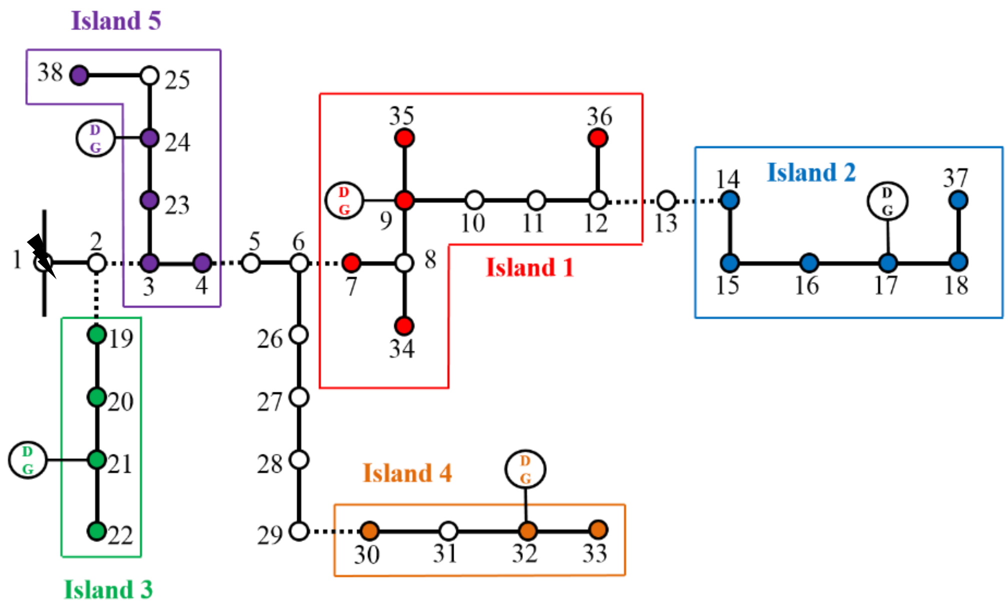
Communication between the agents transfers the information required to determine the restoration strategy

Restoration strategy



Results

38 bus distribution system

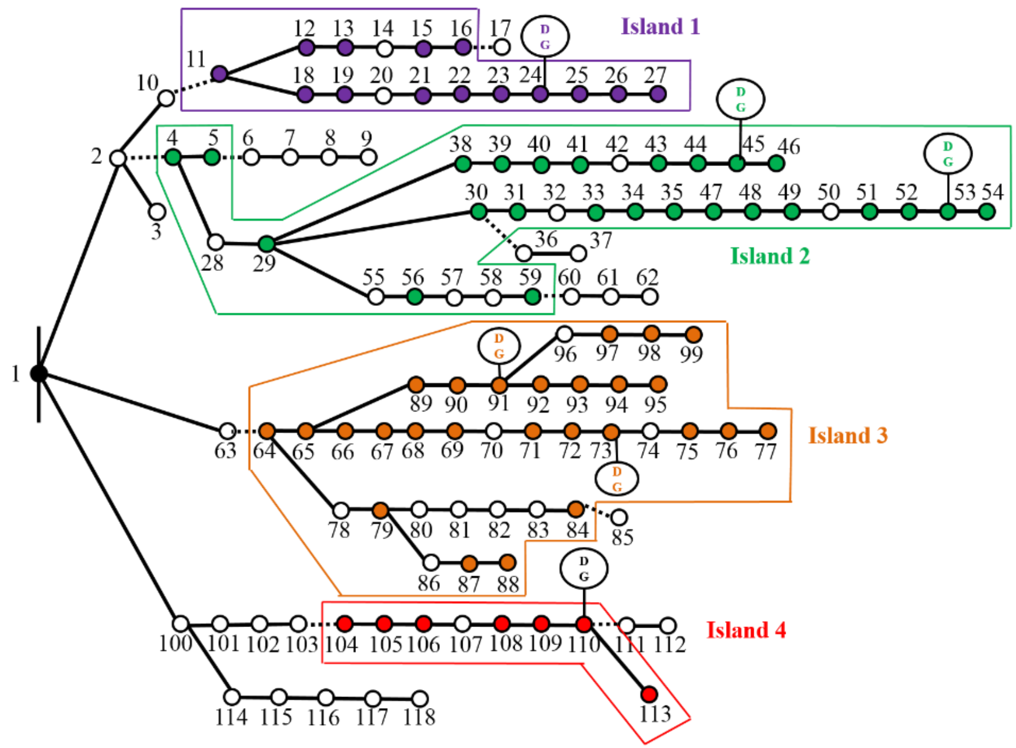


Total priority load restored = 2.2 pu

	Priority load restored (pu)	# of nodes restored	# of switching operations
Island 2	0.39	6	1

Results

119 bus distribution system



Total priority load restored = 11.13 pu

	Priority load restored (pu)	# of nodes restored	# of switching operations
Island 1	**1.15**	**14**	**2**

Inference

- A decentralized MAS framework is developed to solve service restoration problem considering DGs and EVs, to support service restoration

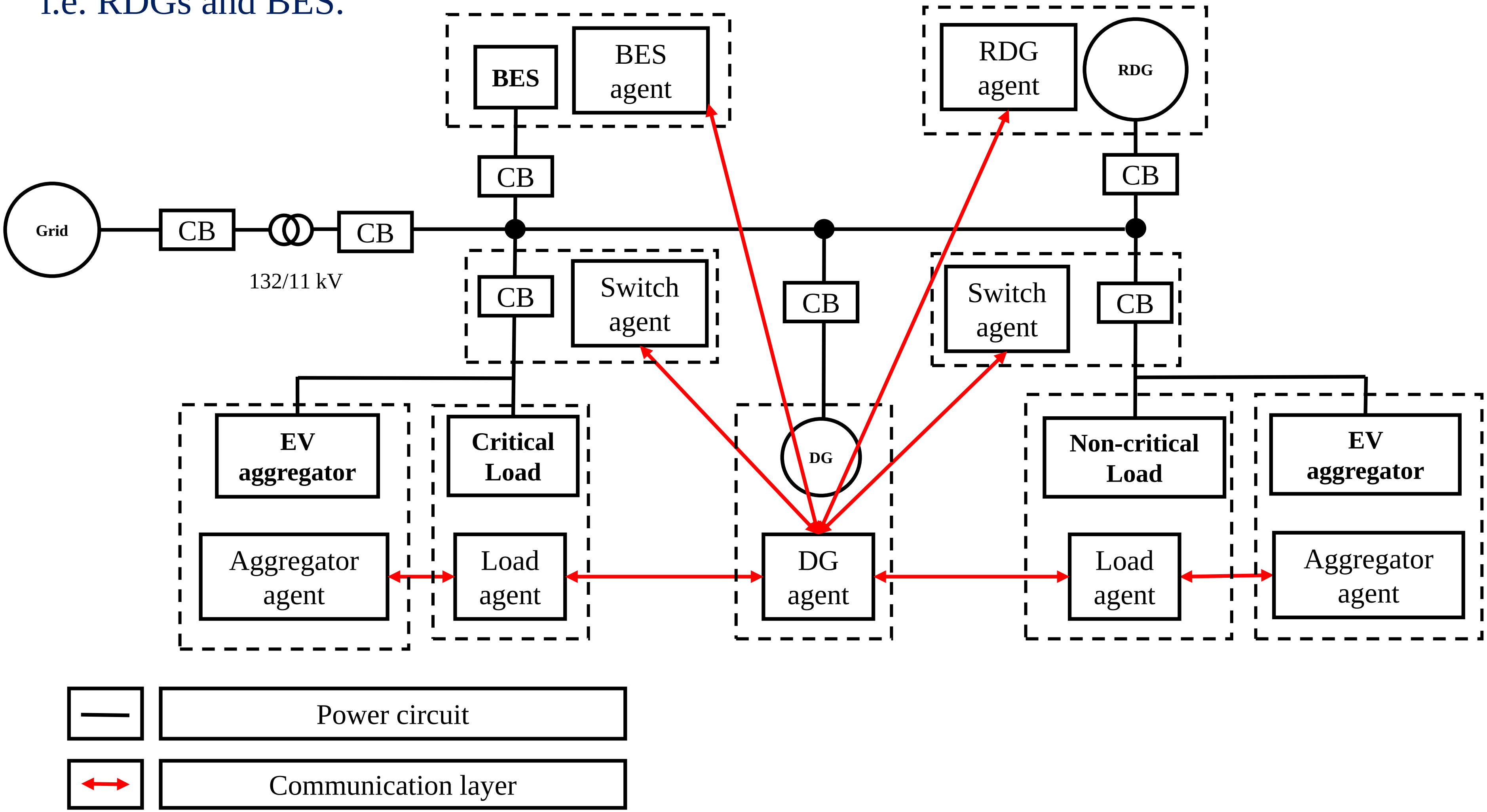
- Competence of the proposed decentralized MAS approach is validated, with advantages:
  - Scalability – can be implemented on large size test systems,
  - Robustness – ability to restore with different DG and EV penetration and work for single as well as multiple fault situations

- The benefits of utilizing V2G feature of EVs for service restoration are demonstrated

A. Sharma, D. Srinivasan, A. Trivedi, "A decentralized multi-agent system approach for service restoration using DG islanding ", Transactions on Smart Grid, vol.6, no.6, pp.2784-2793, Nov. 2015.

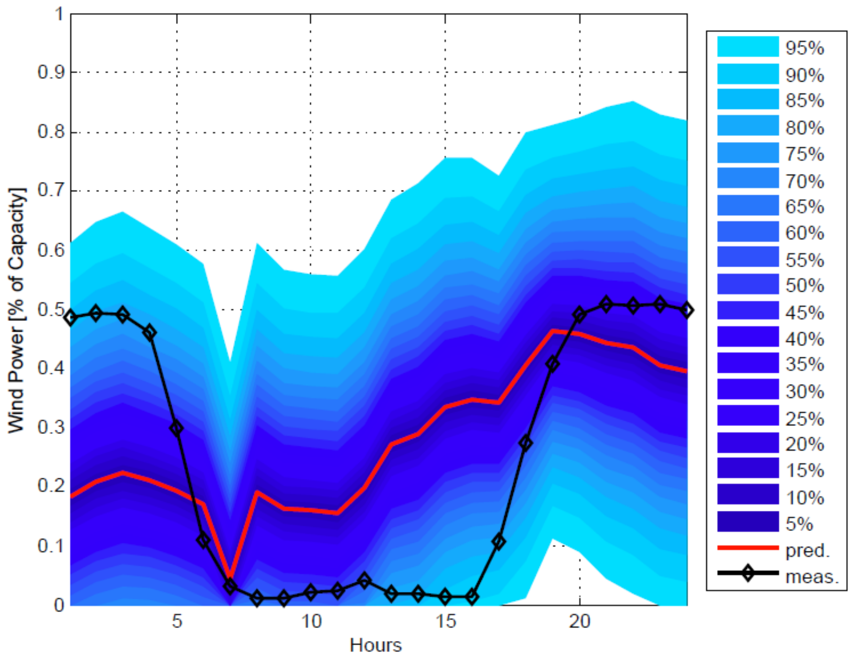
Service Restoration considering uncertainty of load demand and power generated by renewable DGs

The decentralized MAS architecture is extended to include the new system components i.e. RDGs and BES.

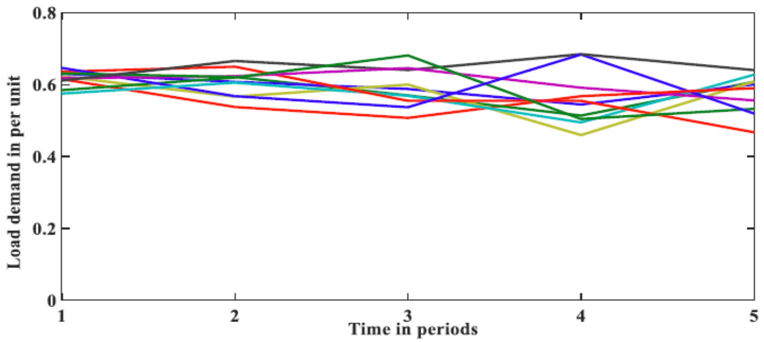


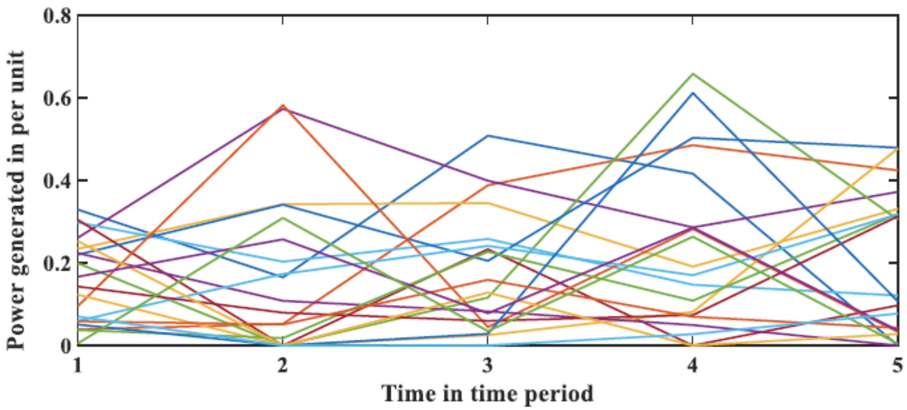
Uncertainty handling and likelihood estimation

- Uncertainty of load demand and power generated by renewable DGs is forecast using scenario generation method based on prediction intervals.



List of prediction intervals





Monte carlo scenarios

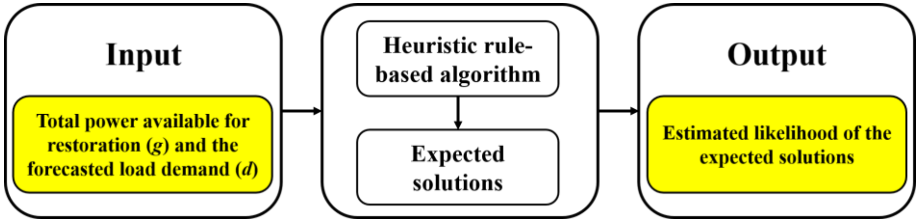
H. Quan, D. Srinivasan, and A. Khosravi, "Short-term load and wind power forecasting using neural network-based prediction intervals," IEEE Trans. Neural Netw. Learn. Syst., vol. 25, no. 2, pp. 303–315, Feb. 2014.
H. Quan, D. Srinivasan, and A. Khosravi, "Incorporating wind power forecast uncertainties into stochastic unit commitment using neural network-based prediction intervals," IEEE Trans. Neural Netw. Learn. Syst., vol. 26, no. 9, pp. 2123–2135, Sep. 2015.

Likelihood estimation

- Manifold Monte Carlo scenarios → provide multiple solutions to the utility for decision making

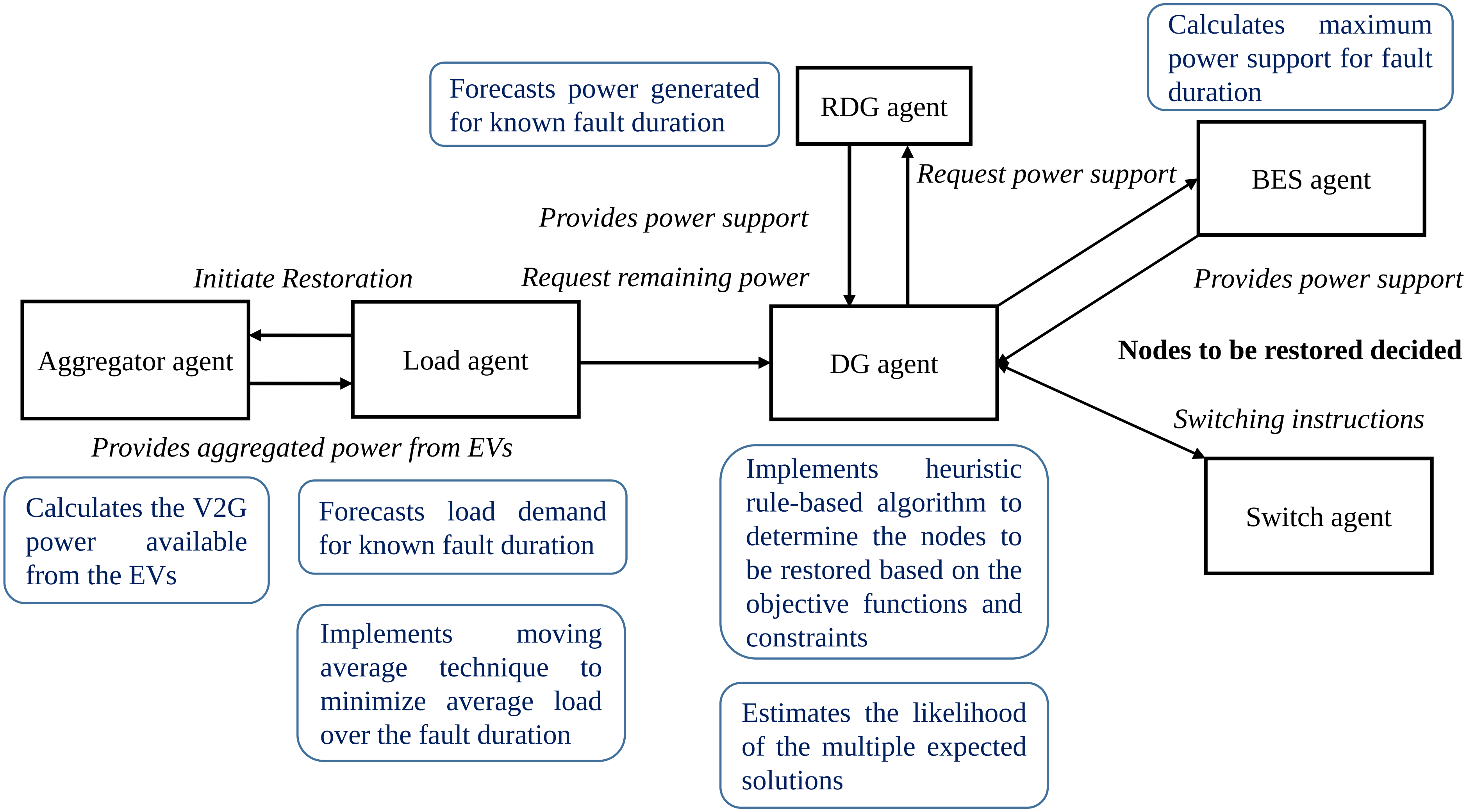
- The maximum likelihood estimator (MLE) is employed to estimate the likelihood of the expected solutions

Likelihood function $L_s(p|\ e(g,d)) = S(e(g,d)|p_S)$



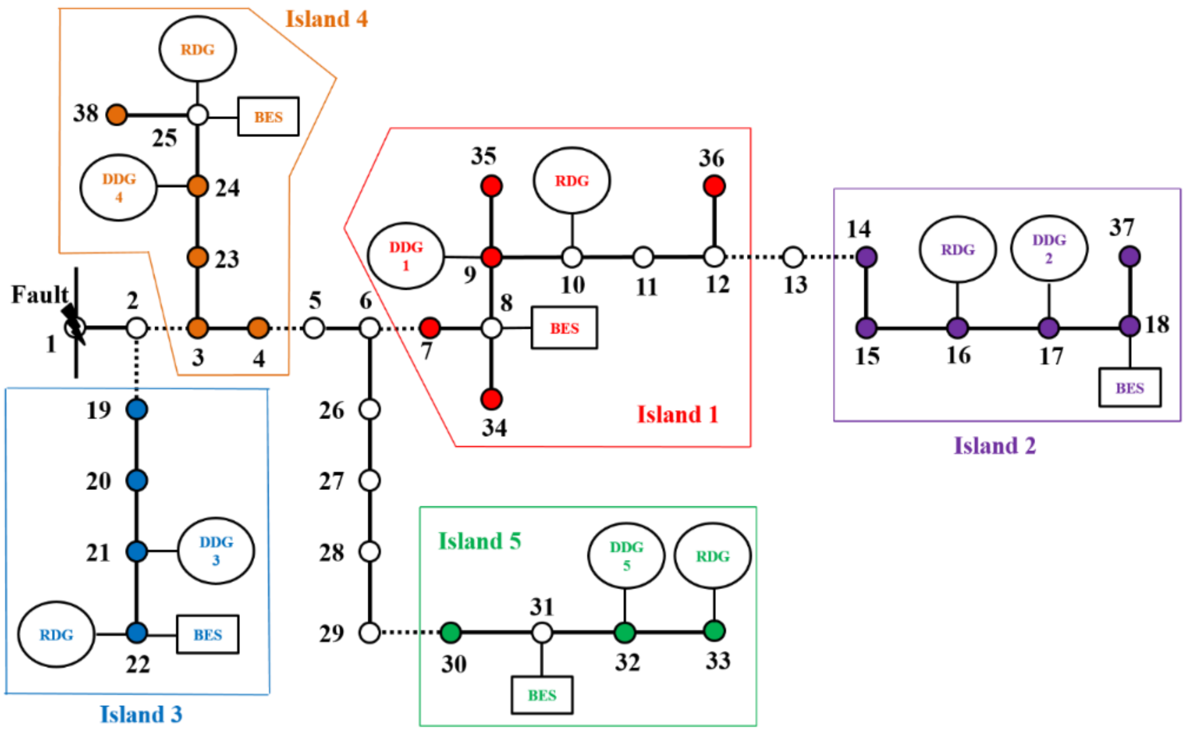
The likelihood estimation process

Restoration strategy



Results

38 bus distribution system



# of nodes restored = 23

# of switching operations = 7

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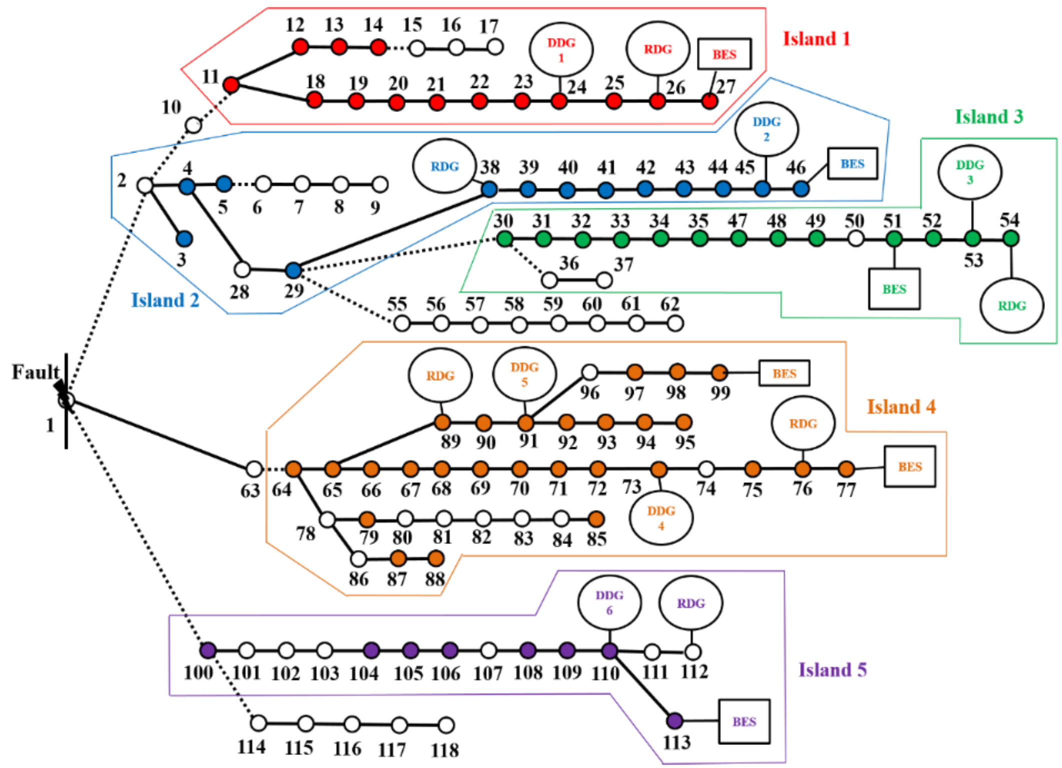
Results

119 bus distribution system



# of nodes restored = 73

# of switching operations = 14

"Demand data Singapore region," 2014 [Online] Available: https: //www.emcsg.com/marketdata/priceinformation#priceDataView
"Wind dataset by DOE," 2014 [Online] Available: http: //transmission.bpa.gov/business/operations/wind/.
"Solar data Alabama region," 2014 [Online] Available: http: //www.nrel.gov/electricity/transmission/solar_integration_methodology.html.

Results

Compare 3 cases: no EVs, no BES, both EVs and BES

38 bus system – DDG1

Cases	No. of nodes restored	No. of switching operations	Likelihood estimate	Priority order of nodes restored
No EVs	7	2	0.82	1,4-6,8-10
No BES	6	2	0.61	1,4,5,8-10
Both EVs and BES	5	2	0.76	1,2,8-10

No EVs – BES compensates system uncertainties

No BES – EVs compensate only load uncertainty

Both EVs and BES – restore node with priority 2

119 bus system – DDG1

Cases	No. of nodes restored	No. of switching operations	Likelihood estimate	Priority order of nodes restored
No EVs	14	2	0.94	1-8,10-15
No BES	11	2	0.71	1-8,10-12
Both EVs and BES	13	2	0.89	1-13

Inference

- A decentralized MAS framework is developed to solve service restoration problem considering the uncertainty of load demand and power generated by RDGs

- Competence of the proposed decentralized MAS approach is validated, with advantages:
  - Scalability – to work for different size test systems,
  - Robustness – ability to work for different load demand and RDG generation profiles

- The benefits of deploying BES and EVs to alleviate system uncertainties are highlighted

<u>A. Sharma</u>, D. Srinivasan, A. Trivedi, "A decentralized multi-agent system approach for service restoration in uncertain environment", Transactions on Smart Grid, accepted.

Service Restoration Considering Uncertainty of Outage duration

- Outage duration is an uncertain quantity
- Depends on : cause of the fault, region affected by the fault, time of fault, reason of fault, availability of crew for repair etc.
- More important because of uncertain power generation from RDGs and limitations of energy storage

Solution approach

- Outage duration data is clustered on the basis of cause of fault
- Probabilistic analysis is used for uncertainty handling and decision making
- A restoration index is proposed, based on priority of node restored, number of switching operations, and MLE of the restoration solution

Work under review

Future work

- Extension of Service restoration problem
  - Include fault detection and isolation to develop a self healing system
  - Sizing and siting of distributed energy resources to assist restoration

- Extension of multi-agent system approach
  - Implement proposed MAS framework on RTDS
  - Implement learning ability in the agents

Conclusion

Summary to ANM prospects

- It will play a vital role in the smart grid vision
- A solution to make renewable integration a viable solution: economically as well as technically
- Open to new technologies: distributed energy storage and demand response
- Solutions require:
    - Standards for uniformity
    - Fast acting control hardware
    - Real time decision making
    - Communication protocols

Thank you